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Real-Time Expressive Rendering of City Models

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Abstract

City models have become central elements for visually communicating spatial information related to urban areas and have manifold applications. Our real-time non-photorealistic rendering technique aims at abstract, comprehensible, and vivid drawings of assemblies of polygonal 3D urban objects. It takes into account related principles in cartography, cognition, and non-photorealism. Technically, the geometry of a building is rendered using expressive line drawings to enhance the edges, two-tone or three-tone shading to draw the faces, and simulated shadows. The edge enhancement offers several degrees of freedom, such as interactively changing the style, width, tilt, color, transparency, and length of the strokes. Traditional drawings of cities and panoramas inspired the tone shading that achieves a pleasing visual color effect. The rendering technique can be applied not only to city models but to polygonal shapes in general.

1. Introduction

In this article, we describe a technique for real-time expressive rendering of city models. As main elements of virtual urban 3D environments, city models represent geometry and appearance of buildings of urban areas as well as their surroundings. Figure 1 illustrates the kind of visualization achieved by the presented real-time expressive rendering technique for city models.

City models have been investigated for many years in geo sciences, focusing on acquisition, classification, and analysis of urban data derived from, for example, laser scans or aerial photography. For instance, Ribarsky et al. describe in detail methods for urban data acquisition and classification. In computer graphics, interests focus on rendering and modeling techniques for virtual 3D environments. In particular, photorealistic representations are used in many applications; they require and, therefore, depend on a large amount of geometric and graphical detail to achieve impressive results, and have to cope with the resulting geometric and graphical complexity of city models. The lack of sufficient detail is often frustrating – not because highly detailed data would actually be required at early stages of construction but because without such detail the visual results are not convincing. For many applications, however, the virtual-reality paradigm is neither cognitively adequate nor adequate with respect to the task to be supported by interactive visualizations.

In cartography, the visual representation of urban spatial information has a long history and has yielded many principles for drawings of this category. The most prominent examples include panoramic maps of cities and landscapes as well as bird's-eye views of cities. They show a high degree of visual clarity and geometric abstraction – preferring abstraction to realism. The historic maps in Figures 2 illustrate a few principles of their design: choosing colors carefully; simplifying geometric structures; and sketching dimensions of and relationships

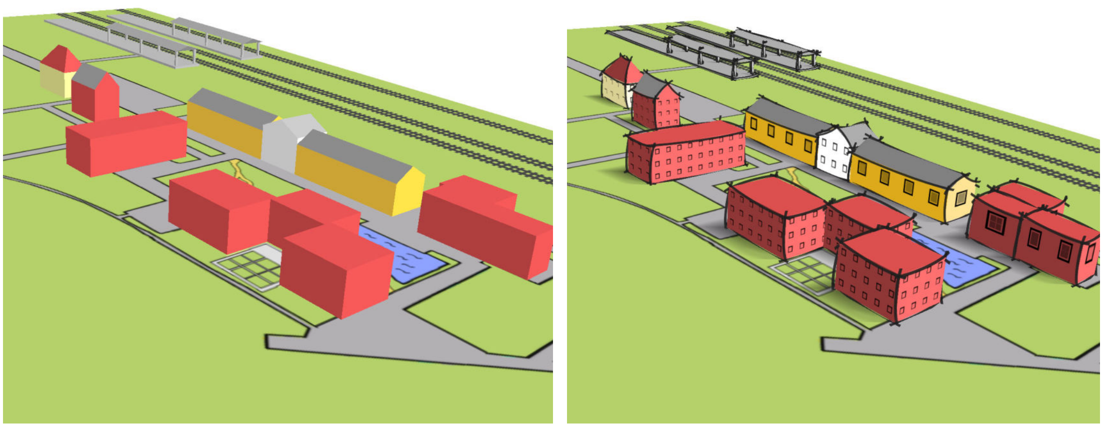

Figure 1. Part of a 3D city model. Presentation based on standard illumination (left). Presentation based on real-time expressive rendering with enhanced edges, integrated shadows, and procedurally generated facades.


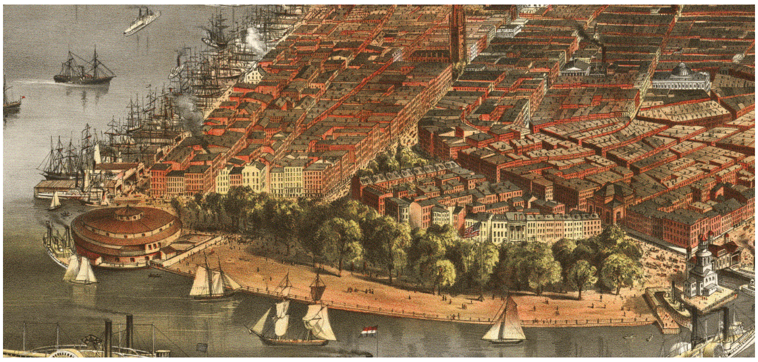

Figure 2: Map of the City of Graz, Austria, 16th century (left). Map of the City of New York, 1870 (right).

between objects. Their rich contents and visually pleasing design triggers the curiosity of the observer.

The manifold applications of expressive renderings of city models include decision-support systems for city and landscape planning to show locations and relations between parts of the model. Furthermore, city models serve as architectural development models used to illustrate concepts and principles underlying suggested plans. City models may facilitate people's participation in decision-making through comprehensible representations. In geo-information systems, transport information systems, and radio-network planning systems city models play a fundamental role in visualizing data and monitoring processes related to urban areas. Further applications can be found in education and entertainment – imagine a cartoon-like story taking place in a 3D non-realistically drawn "real city" or an Internet platform for neighborhood communication.

On the whole, city models act as main subjects used for presenting, exploring, analyzing, and editing spatial information. For these purposes, real-time rendering is required to achieve interactive visualization.

The expressive rendering technique for city models we discuss intends to reflect insights from cartography and cognitive sciences. We have designed a real-time rendering technique that processes polygonal 3D objects, the typical elements of city models. It achieves abstract, comprehensible, and vivid illustrations of assemblies of those objects.

2. Cartographic and Cognitive Aspects of City Models

We have analyzed the rendering of city models from the perspective of cartography, cognition, and non-photorealism. We derived several principles that are found in many non-digital drawing techniques.

City Models as Maps. City models can be considered as map-related 3D representations of spatial data. In addition to 2D information, such as topographic maps, thematic maps, and 2D ground plans, they include 3D information, for example, 3D terrain models and 3D buildings. Interactive representations allow for better exploration and analysis, but complicate navigation and orientation, unless special care is taken to support these user activities.

Geometric Projection. In classical bird's-eye views both orthogonal and perspective projections are used. The Bollmann's maps of many European as well as US cities are well-known examples of 'pictorial city maps'. Traditionally they choose the east or west direction for projection because important, optically dominant landmarks such as well known public buildings and churches are oriented that way. In addition, map designers often attempt to diagonally capture important quarters and streets of houses. Whatever direction is taken, approximately half of the model is not shown in static views. Thus an interactive 3D city map can achieve a substantially better communication of spatial information.

Graphical Techniques. Maps of city models attempt to maximize visual clarity. Most importantly, edges are enhanced to stress the contours of buildings. Colors are chosen according to semantics and aesthetics – they do not necessarily correspond to the natural colors. The overall number of colors is kept small. Strothotte et al. (1994) propose graphical techniques of a sketch rendering system based on insights from perceptional psychology.

Geometrical Techniques. The terrain model represents the reference surface for city models. In traditional city maps, the terrain surface is often ignored or just indicated where its morphology is significant. For interactive visualizations, a 3D terrain model can improve the understanding of the city model and the related terrain; its impact on the visualization can be controlled by appropriate scaling of the terrain surface. To cope with complex geometry, detail reduction is used both at the technical level by multiresolution modeling and level-of-detail techniques, and at the semantic level by generalizing buildings to quarters if their distance to the camera exceeds a given threshold.

As the sides of buildings provide more characteristic information about them than the roofs, the roofs can be scaled down in height while the main bodies of the buildings are scaled up. This is done in traditional panoramic views of cities to meet the spectator's expectation, who is used to seeing the city as a pedestrian.

Orientation Cues. In a complex and dense urban area landmarks serve as means of orientation for the user. Landmarks consist mainly of those buildings that are known a priori to the user – typically monuments and buildings of public interest. Therefore, they require an exact geometric and graphical 3D model. The visualization should guarantee that landmarks, even if they are nearly out of the view volume, do not disappear. The multiresolution mechanism might want to treat them differently from the remaining buildings because the eye is sensitive to even small changes of well-known objects.

Shape Cues. In many visualizations, shape is derived from shading. In abstract depictions, shades are rarely used to communicate that information. Instead, contours and edges are drawn. In particular, edge enhancement is used for separating the faces of an object.

Depth Cues. In classical 3D city maps, using orthogonal projections the monocular depth cues linear perspective, relative size and, texture gradient are not available. However, occlusion and known sizes provide depth cues. Frequently map designers place objects of known size (e.g., people, trees, animals) in the scenery. Furthermore shadows and fog can be used to aid depth perception. Interactive visualization additionally provides motion-based depth cues. Goldstein (1999) and Ware (2000) give a comprehensive overview of depth cues.

3. Rendering City Models

Rendering techniques for city models have to cope with their geometric and graphical complexity. Typically the model does not fit into main memory and cannot be rendered in real-time in its original precision. City models are therefore subject to multiresolution modeling and acceleration techniques as described by Willmott (2001) and Flack (2001).

Common acceleration techniques include view-frustum culling and occlusion culling to reduce non-visible geometry from being processed by the rendering pipeline.

Level-of-detail modeling for buildings is required. But their geometry can be fragile, that is, small geometric details of a single building, for example, two columns beside the front door, might be important for recognizing a single building. For this reason, general multiresolution algorithms simplifying a single, geometrically complex 3D object cannot be directly applied – semantics of building parts and visual perception issues such as shading discontinuities [1] have to be taken into account. Generalization can further define how to collapse the buildings of a quarter into a quarter bounding box. In cartography, this discrete form of generalization has been developed to avoid artifacts resulting from too many too small buildings, and they improve the comprehensibility of a city model.

Expressive line drawings are a major topic in NPR. For instance, Raskar (2001) presents a technique for rendering silhouettes, ridges, and valleys of a polygonal scene using graphics hardware abilities. The silhouettes are rendered by enlarging the corresponding faces. For the ridges and valleys additional quadrilaterals are to be added at run-time. We follow this approach. Our implementation in contrast uses preprocessing since polygon generation is not yet supported by current graphics hardware. For achieving expressiveness, we texture the quads, as proposed by Raskar. For this we need planar surfaces, and therefore use billboarding.

Strothotte and Schlechtweg (2002, Chapter 3) give a comprehensive overview of drawing lines, curves, and strokes. He distinguishes between the path and the style of lines. The path describes the geometric position of the line, and the style the overall appearance. Our expressive line drawing technique treats paths given as the vector from the starting point to the end point of an edge. The style is conveyed using textures. Examples of stroke textures are illustrated in Figure 3.

4. Modeling City Models

Our real-time expressive rendering technique is based on an object-oriented design of city models. In this article, we concentrate on the rendering of buildings, so we only briefly outline principles of such a design.

The reference surface is partitioned into *patches* that are derived as the dual of the graph of the street network. The resulting patches are empty (e.g., streets) or equipped with buildings or other urban objects such as vegetation.

In each equipped patch, there is a (possibly empty) collection of *buildings*, each of which is specified by 3D geometry. The design also specifies the relation between geo database and urban objects such as buildings, streets, and patches. For each building, we classify its *object edges* according to their structural importance and semantics.

Among the important attributes of buildings, we specify the ground plane, height, and roof style, where the roof style is chosen according to a given classification. We are currently working with a simple classification consisting of the roof styles flat, hip, gable, or pyramid illustrated in Figure 4.

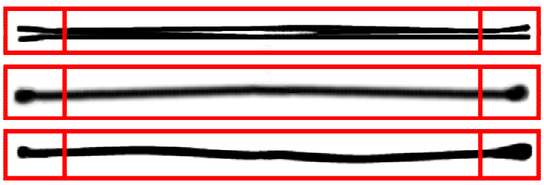

Figure 3: Examples of stroke textures.

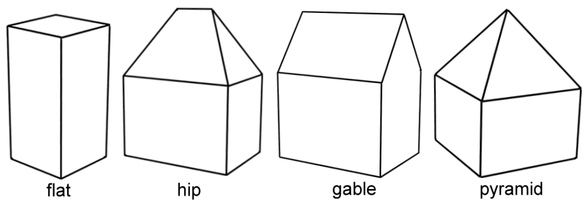

Figure 4: Classification of roof styles.

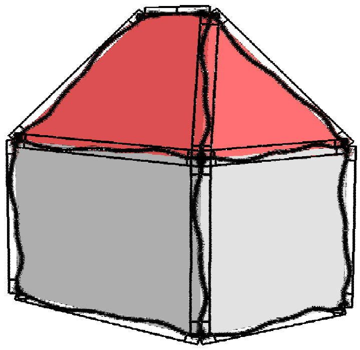

Figure 5: Edge-aligned billboards.

5. Expressive Rendering of City Models

Edge enhancement, as one of the aspects of our rendering technique, operates in object-space. For each edge to be drawn, we create on-the-fly an edge-aligned quad facing the viewer, and use textures to simulate strokes.

Textured Strokes. We draw the edges using thin rectangular billboards fastened to or near to the start and end points of the edges as in Figure 5. The billboards are drawn using a stroke texture that can be partially transparent. We decompose each edge into three segments: start segment, middle segment, and end segment. For each, different stroke textures can be configured. The texture for the middle segment is repeated according to the length of the stroke. The stroke texture defines the style of strokes. A transparency parameter controls the weight that is given to edges in an image. This way, edges can be faded in and out.

Billboards. Given the start and end points of an edge, we want to draw a sketchy line along the edge. In hand drawings, lines along edges usually do not start and end exactly at the ends, but near the ends. This results in a higher visual quality and expressiveness. Inspired by this, we introduced two rendering parameters, one determining the tilting angle and one the length of the line. To express uncertainty, tilting and length can be varied as illustrated in Figure 6.

After moving the starting and end points according to the tilt and length parameter, we apply cylindrical billboarding, using the vector from the starting point to the end point as an axis. For implementation, we can employ per-vertex programming for calculating the billboards.

Controlling the Edge Style. Edge drawing in object-space allows us to control appearance attributes such as stroke form, stroke width, brightness, color, length, and exactness. For example, the actual drawn edge can be stretched, shrunk, or disturbed to express fuzzy, sketchy, or slightly overlapping outlines. The object-space approach offers a high degree of expressiveness, in particular, if the underlying model explicitly defines edges as in city models.

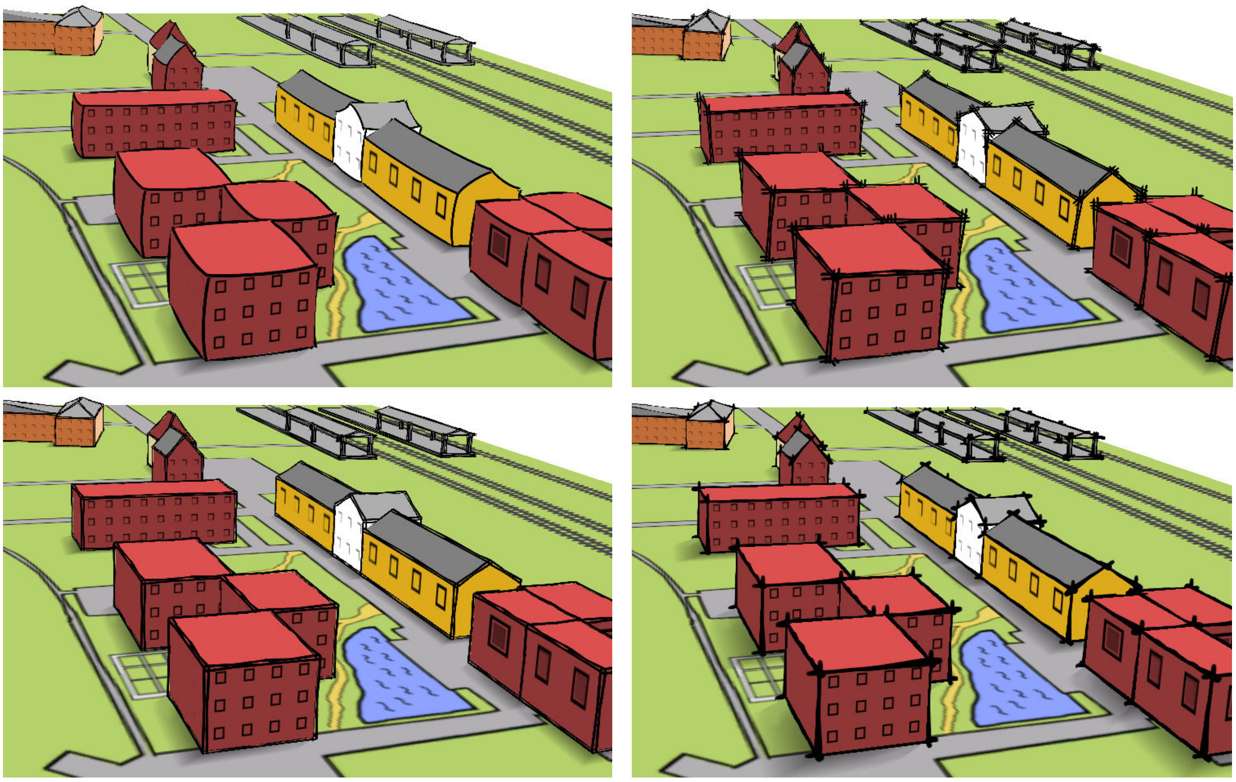

Figure 6: Combining different stroke textures, stroke lengths, and tilts to achieve different looks.

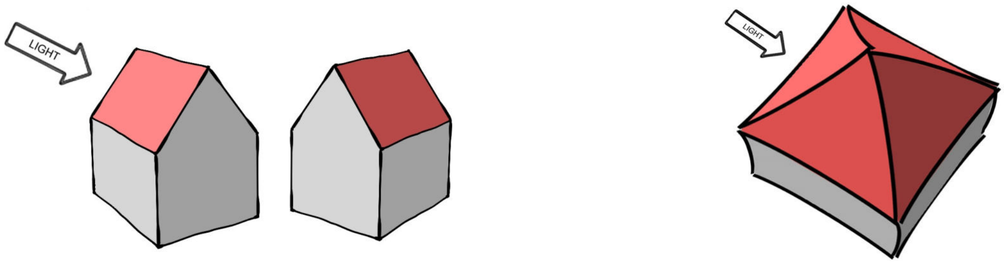

Figure 7: Two-tone shading (left). Three-tone shading (right).

When rendering a complex scene we do not always want to draw all edges and not necessarily all edges with the same level of detail. For instance in our implementation we draw only the edges that are best visible to the viewer using three textures as explained above. Edges with low visible importance are either drawn using only the texture for the middle or not at all; as criteria the actual length of an edge in image space and the distance to the camera can be used.

6. Tone Shading for City Models

A major inspiration for our work were cartographic picture maps and other hand drawings of cities. In colored drawings the illustrator usually abstracts from the realistic colors of the urban objects and greatly reduces the number of colors used in the representation. In general only two or three colors and for each color only two or three tints are used. The choice of the colors is based on aesthetic and other reasons as well as the actual colors of the city. Inspired by this we decided to use a two-tone or three-tone shading for the faces, which assigns the color according to the angle of the face to the light as illustrated in Figure 7. Technically this can be done in the same way as cartoon shading but instead of the intensity we use the dot product of the normal of the face and the light direction to determine the color.

We observed that three tone shading supplies better results for interactive applications than two tone shading because neighboring faces of one building will have different colors assuming the building does not have more than four sides. Using two-tone shading this is not the case. Thus there is much less contrast when moving through a scene and the light direction is much harder to determine. This, of course, is not a problem in traditional cartography where the scenes are static and the light direction can be chosen suitably. Often the light shines from the upper left. This can also be done with our shading when producing static scenes.

7. Shadows in City Models

In architectural drawings shadows are used for conveying three-dimensionality and spatial relationships, which aids the comprehensibility and naturalism, and, for adding vividness. For example, the length of shadows represents a measure for the heights of the buildings. Shadows should not obscure any parts of the geometry. Also they should harmonize with the rest of the drawing and be clearly recognizable.

There are different types of shadows in computer graphics: Hard shadows are derived by building a geometric shadow volume. Within that volume, all scene parts are drawn darker. Soft shadows are conceptually similar except that the darkness varies, a blurred impression results. Ware (2000) argues that soft shadows do not need to be physically correct in order to be convincing and recommends using soft shadows instead of hard shadows.

In our approach, we simulate shadows by adding textured-quads to the ground plan of each building in

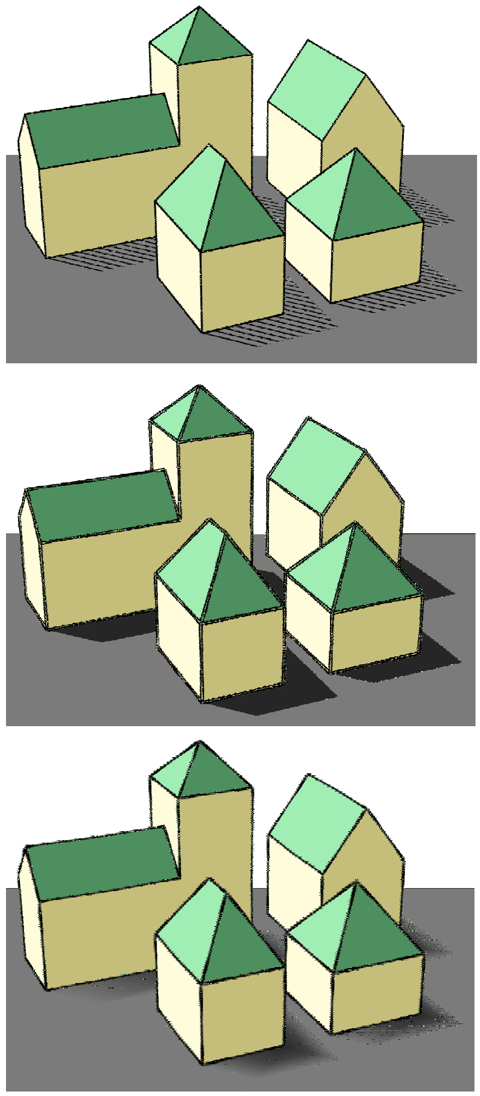

Figure 8: Three types of shadows: hatched, hard and soft.

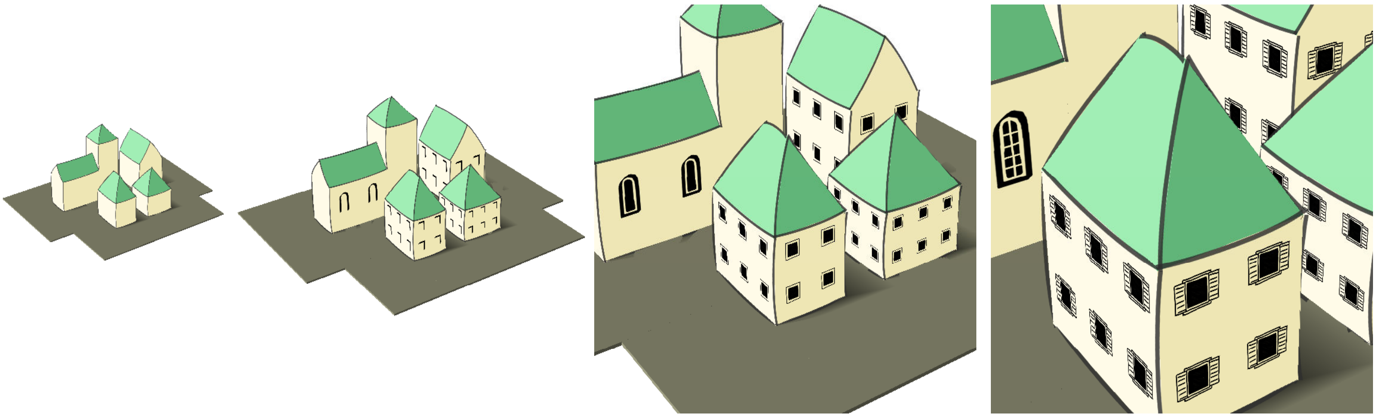

Figure 9: Level-of-detail textures for windows, selected according to camera distance.

the direction of the projected light direction to draw the shadowed region on the reference surface. Self-shadowing and shadowing between faces are ignored: shadows are only calculated with respect to the reference surface. We support three types of shadow, hard shadows, soft shadows, and hatched shadows as shown in Figure 8. The hatched shadows are a typical element of architectural drawings (Mehlhorn, 1994).

8. Current Directions

The real-time expressive rendering technique presented here focus on representations of virtual 3D city models. As core features, it uses edge enhancement together with tone shading and shadows. The rendering technique offers many degrees of freedom for individual sketch styles and expression of uncertainty and vagueness. Its implementation can be completely accelerated by today's graphics hardware.

We also added support for height cues such as procedural textures that indicate windows. Their main purpose is to depict heights and to allow users to compare and to estimate building heights. Figure 9 illustrates the concept, which is based on level-of-detail 2D textures that encode window representations generalized differently.

The presented technique can be extended in various directions. 1) A generalization scheme, driven by semantics, could be added to simplify city models at the geometric level; the generalization should take into account cartographic and architectural methods. 2) The faces could be designed to express information about the façade. For this, textures derived from photos or images taken from the real model could be preprocessed in such a way that the core information is made available for expressive rendering. 3) Edge enhancement for curved surfaces should be investigated with respect to a method that can be accelerated by graphics hardware and implemented by per-vertex programs.

Acknowledgments. We would like to thank Kevin Buchin and Marc Nienhaus for their collaboration, and Christian Herrmann for his cartographic inspiration.

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